X-693-75-284
PREPRINT

NASA TM X- 71014

DIRECTIVITY OF LOW FREQUENCY SOLAR TYPE III RADIO BURSTS

R. J. FITZENREITER
J. FAINBERG
R. B. BUNDY

(NASA-TM-X-71014) DIRECTIVITY OF LOW FREQUENCY SOLAR TYPE 3 RADIO BURSTS (NASA) 20 p HC $3.50 CSCL 03B

N76-11986

Unclas
G3/92 02223

OCTOBER 1975

GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

DIRECTIVITY OF LOW FREQUENCY SOLAR TYPE III RADIO BURSTS

R.J. Fitzenreiter, J. Fainberg and R.B. Bundy*
Radio Astronomy Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The occurrence rate of type III solar bursts in the frequency range 4.9 MHz to 30 kHz is analyzed as a function of burst intensity and burst arrival direction. We find that a) the occurrence rate of bursts falls off with increasing flux, S, according to the power law $S^{-1.5}$, and (b) the distribution of burst arrival directions at each frequency shows a significantly larger number of bursts observed west of the Earth-Sun line than east of it. This western excess in occurrence rate appears to be correlated with the direction of the average interplanetary magnetic field, and is interpreted as beaming of the observed burst radiation along the magnetic field direction.

*Presently at the University of Maryland, College Park, Maryland

1. INTRODUCTION

Type III radio bursts viewed from different directions provide important information on effects relating to propagation conditions in the corona and to the burst emission process. The directivity of an individual burst can be obtained from simultaneous observations of the burst from several locations which subtend a wide angle from the source. Such measurements have been made by the STEREO experiment at meter wavelengths (Caroubalos et al., 1974) in which the observing locations were the Earth and a distant space probe. An alternate method for obtaining directivity information is by statistical studies of burst distributions over observing directions made from a single location. Previous ground-based and satellite observations of burst distributions for source levels close to the Sun show a higher occurrence rate and a greater intensity of emission at the center of the solar disk than at the limb indicating radially directed emission (Wild et al., 1959; Fainberg and Stone, 1974). Kaiser (1975) has compiled distributions of measured arrival directions of solar emission observed by the IMP-6 satellite corresponding to emission levels over

the range 25 $R_{\odot}$ out to 1 AU. For source levels out to ~125 $R_{\odot}$ he finds a small but significantly higher occurrence rate for emission observed west of the Sun-Earth line. Since these observations extended over a period of more than 18 solar rotations, it is likely that variations in the production of bursts with respect to solar longitude were averaged out. In Kaiser's study, the east-west asymmetry in occurrence rate seems to indicate beaming of the solar burst emission along a non-radial direction.

The present paper is an analysis of individual solar bursts observed by IMP-6 during a three-month period when the satellite orbit was such that there was minimal interference from the Earth radio emissions described by Kaiser and Stone (1975). In this paper, we find a definite western excess of burst arrival directions. In addition, there is a possible correlation between this western excess in burst occurrence rate and the average spiral magnetic field direction. We also find that the occurrence rate of bursts falls off with increasing flux, S, according to $S^{-\beta}$. The observed distributions of burst intensities and arrival directions are then used to estimate the angular width of the burst radiation pattern assuming that the axis of the radiation pattern is along the average magnetic field direction.

2. OBSERVATIONS AND RESULTS

In this study of type III bursts two distributions were investigated. In section 2(a) we discuss the distribution of burst arrival directions and in section 2(b) we discuss the distribution of

burst intensities.

(a) The distribution of burst arrival directions.

The arrival direction of burst radiation is measured by the IMP-6 experiment using the modulation imposed on the observed radio flux as a result of the spin of the satellite. The source direction determined is the solar elongation, which is the arrival direction projected into the plane of the ecliptic and measured relative to the Earth-Sun line. A description of the procedure used is given by Fainberg et al. (1972) and Fainberg (1975).

The observed elongation distributions of all bursts observed during May, June, and July 1971 are given in Figure 1 for several frequencies in the observing range. The enhancement in the distributions near the east and west limb are due to a statistical effect that has been discussed by Kaiser (1975). Near the limb, a wide range of solar longitudes corresponds to nearly the same elongation, thus, enhancing the number of bursts observed near the limb. The effect should be symmetric with respect to the Earth-Sun line (dashed line). The observed burst distributions are clearly not symmetric, however, and show that there is an excess of bursts measured in the West. The bursts observed in this study originated primarily from two active regions on the Sun which recurred with each solar rotation during the observing period. It seems reasonable to expect that three solar rotation periods is a sufficiently long time for variations in the production of bursts to be smoothed out in solar

longitude. In this case the western excess may be due to an effective beaming which allows more bursts to be observed west of the Earth-Sun line. The interpretation that beaming accounts for the observed asymmetry, rather than a solar longitude effect in burst activity, is supported by data obtained during another time period, May, June, and July, 1972. Burst distributions during this period show the same relative excess of bursts observed in the West.

This east-west asymmetry suggests an association with the spiral interplanetary magnetic field because the average field is directed at the Earth only for western elongations. The relevant geometry is given in Figure 2. The mean elongations of the burst distributions (Figure 1) are a quantitative measure of the asymmetry and are plotted in Figure 3 for each frequency. The abscissa is the distance from the Sun of the emission level corresponding to each frequency, assuming an emission level scale based on the extrapolation of levels determined by the RAE-1 satellite (Fainberg and Stone, 1971) out to 1 AU. The solid curve in Figure 3 is the calculated elongation of an average spiral magnetic field line when the field at a given distance is directed at the Earth. It appears that the mean of the distribution of arrival directions may be correlated with the average magnetic field direction over a wide range of source distances from the Sun. In order to examine the distribution of bursts relative to the average magnetic field direction, the burst distributions have been expressed in terms of γ, the angle between the field direction

and the observing direction. The angle γ for each burst is obtained from the measured elongation and the assumed emission level using the geometry in Figure 2.

The γ-distribution of bursts is given in Figure 4 for three representative frequencies. The distributions in Figure 4 are approximately symmetric with respect to $\gamma = 0$ (direction of the average magnetic field) even though some effects of the statistical limb enhancement may be present. A measure of the width of the distributions is given by the standard deviation which is approximately 40° and is constant to within a few degrees over the observing frequency range of 1030 kHz to 130 kHz.

(b) The distribution of burst intensities.

The distribution of burst peak intensities over the three-month observing period is given in Figure 5 for one observing frequency, 815 kHz. The ordinate is the number of bursts observed per day per unit flux ($w\ m^{-2}\ Hz^{-1}$). The distribution is normalized such that the integral over the data multiplied by 90 days is equal to the total number of bursts observed at the given frequency. The solid line is the least squares fit to all but the first point. This point was omitted because it corresponds to the bursts observed close to the threshold detection level which are difficult to measure. The distribution obeys the power law, $n = AS^{-\beta}$, where n is the occurrence rate and S is the observed radio flux. The constants A and β obtained by the least squares fit and the total number of bursts observed at representative frequencies are given in Table 1. The index β varies

systematically between 1.7 and 1.2 as frequency decreases from 4.9 MHz to 110 kHz. This variation in β corresponds to a flattening of the distribution at low frequencies which is at least partially due to observing conditions affecting the identification of low-amplitude bursts. The average value of β is 1.5. These distributions are in agreement with the groundbased observations of several observers at meter wavelengths in which the intensity distributions of bursts also fit a power law with an index equal to 1.5 (Steinberg and Caroubalos, 1970).

3. DISCUSSION

The dependence of the number of observed bursts on viewing direction is a result of the directivity of the burst radiation and the decrease in occurrence rate with increasing intensity. Bursts that are viewed in a direction other than the direction of maximum intensity will be reduced in intensity and there will be a corresponding reduction in the number of bursts measured above the threshold detection level. If a direction for the radiation axis is assumed, then the angular half-width, $_{D}$, of the burst directivity pattern, $D(\gamma)$, may be estimated. The directivity is defined as the intensity in a given observing direction relative to the intensity along the axis of the radiation pattern. Following a discussion by Steinberg and Caroubalos (1970), it can be shown that the number of bursts observed in a given direction, γ, relative to the number observed in the direction of the intensity maximum is given by

$$N(\gamma) \propto \int_{B/D(\gamma)}^{\infty} S^{-\beta}\, dS, \qquad (1)$$

where $S^{-\beta}$ is the probability that a burst is produced with flux S and B is the flux detection level. Assuming (a) that the index β and the proportionality constant implied in Equation (1) are independent of γ, (b) that the axis of the directivity pattern is along $\gamma = 0^{\circ}$, and (c) that the observed burst distribution $N(\gamma)$ and directivity pattern $D(\gamma)$ are Gaussian, then it can be shown that the half-width, σ_D, of the directivity pattern is given by $\sigma_D = \sqrt{\beta - 1}\sigma_N$, where σ_N is the standard deviation of the observed burst occurrence distribution. For the observed value of $\sigma_N = 40^{\circ}$ and the observed range of $\beta = 1.2 - 1.7$, then $\sigma_D = 20^{\circ} - 35^{\circ}$.

This result is consistent with results obtained by Fainberg and Stone (1974) from RAE-1 satellite observations of type III storms. The half-widths of the burst occurrence and intensity distributions over viewing angle, were found to be $\sim 50^{\circ}$ and $\sim 20^{\circ}$, respectively. The symmetry axis of the distribution appeared to be along the radial direction from the center of the Sun. The RAE-1 observations, however, correspond to source levels below 40 solar radii where the deviation of the field line spiral from the radial is small.

The apparent burst directivity may in part be due to a directivity which is intrinsic to the emission process. It is now generally accepted that type III bursts are produced when primary plasma waves generated by the exciter coalesce with oppositely directed secondary

plasma waves. Melrose (1973) has shown that when the secondary plasma waves are generated by scattering of the primary waves by thermal ions, the resulting radio emission is directed into the forward hemisphere of the burst exciter. Thus, the emission is beamed outward along the field lines guiding the exciter. However, a recent theory of type III bursts (Papadopoulos et al., 1974), in which oppositely directed plasma waves are generated by the oscillating two-stream instability, predicts no preference for forward emission. In this latter case, propagation effects alone must account for the apparent directivity.

Ray tracing studies by Steinberg (1972) and Riddle (1974) have shown some of the effects of coronal refraction and scattering on observed burst distributions with viewing angle. The effect of coronal scattering is to broaden the burst distributions. The histograms in Figure 1 show that a significant number of bursts are observed at elongations beyond the limb. Although this may be explained by fluctuations in the assumed emission level, scattering can also cause this effect. The axes of symmetry for refraction and scattering effects are the direction along which the density gradients are maximum and the direction along which the scale sizes of irregularities may be elongated. Close to the Sun, propagation effects will, on the average, be radial. Far from the Sun, however, in the range of IMP-6 observations, the largest density gradients may be associated with density structures such as coronal streamers aligned with the magnetic

field. Density irregularities may also be aligned with the magnetic field. For these reasons, Steinberg (1972) has suggested that averaged propagation effects may be symmetric about the average field direction.

Further analysis of the distributions of bursts out to 1 A.U. is underway in order to take into account propagation effects for various refraction and scattering models in the solar wind.

4. SUMMARY

The distributions of arrival directions and intensities of low frequency type III bursts corresponding to emission levels out to 1 A.U. have been studied. We find that there is a definite excess in the occurrence rate of burst arrival directions west of the Earth-Sun line which appears to be correlated with the average spiral magnetic field direction. We also find that the burst intensities are distributed according to the power law $S^{-\beta}$ at each frequency, where S is the peak burst flux and the average value of the index β is 1.5

The western excess of arrival directions has been interpreted as an apparent beaming of the burst radiation along the direction of the average interplanetary magnetic field. The distributions of burst arrival directions are approximately symmetric with respect to the average spiral magnetic field direction at each frequency and have a nearly constant standard deviation of 40°. The beam half-width of the burst directivity pattern is estimated to be not greater than 35°, assuming the directivity pattern to be Gaussian and centered on the average magnetic field direction.

The causes of the beaming are propagation effects in the solar wind and a possible directivity in the intrinsic burst radiation pattern. There is presently not enough known, however, either about density gradients and field-aligned irregularities or about the burst emission process to assess their relative contributions.

REFERENCES

Caroubalos, C., Poquerusse, M., and Steinberg, J.L.: 1974, Astron. and Astrophys. 32, 255.

Fainberg, J.: 1975, GSFC X-693-75-173.

Fainberg, J., Evans, L.G., Stone, R.G.: 1972, Science 178, 743.

Fainberg, J. and Stone, R.G.: 1971, Solar Phys. 17, 392.

Fainberg, J. and Stone, R.G.: 1974, Space Science Reviews 16, 145.

Kaiser, M.L.: 1975, Solar Phys. (in press).

Kaiser, M.L. and Stone, R.G.: 1975, Science, 189, 285.

Melrose, D.B.: 1973, Astrophys. Lett. 15, 55.

Papadopoulos, K., Goldstein, M.L., and Smith, R.A.: 1974, Astrophys. J. 190, 175.

Riddle, A.C.: 1974, Solar Phys. 35, 153.

Steinberg, J.L.: 1972, Astron. and Astrophys. 18, 382.

Steinberg, J.L. and Caroubalos, C.: 1970, Astron. and Astrophys. 9, 329.

Wild, J.P., Sheridan, K.V., and Neylan, A.A.: 1959, Aust. J. Phys. 12, 369.

Table 1

Distribution of observed burst intensities, $n = AS^{-\beta}$, where S = peak flux ($w\ m^{-2}\ Hz^{-1}$), and n = average number bursts per day per unit flux.

Frequency (kHz)	A	β	Total Number of Bursts Occurring During May-July, 1971
4900	7.58×10^{-14}	1.69	203
3000	1.06×10^{-11}	1.56	318
1630	1.70×10^{-11}	1.56	456
1100	1.01×10^{-10}	1.52	527
815	9.58×10^{-10}	1.47	530
600	6.64×10^{-9}	1.42	486
375	2.97×10^{-8}	1.37	323
250	7.58×10^{-7}	1.29	212
155	1.47×10^{-6}	1.26	131
110	5.92×10^{-8}	1.33	94

Fig. 1 The elongation distributions of bursts observed by the IMP-6 satellite at representative frequencies. The histograms show an excess of burst arrival directions west of the Earth-Sun line (dashed line). The east-west projection of the radio emission surface for each frequency is shown by the heavy horizontal bar. The position of the radio limb (L) is obtained using the assumed emission level scale (see text).

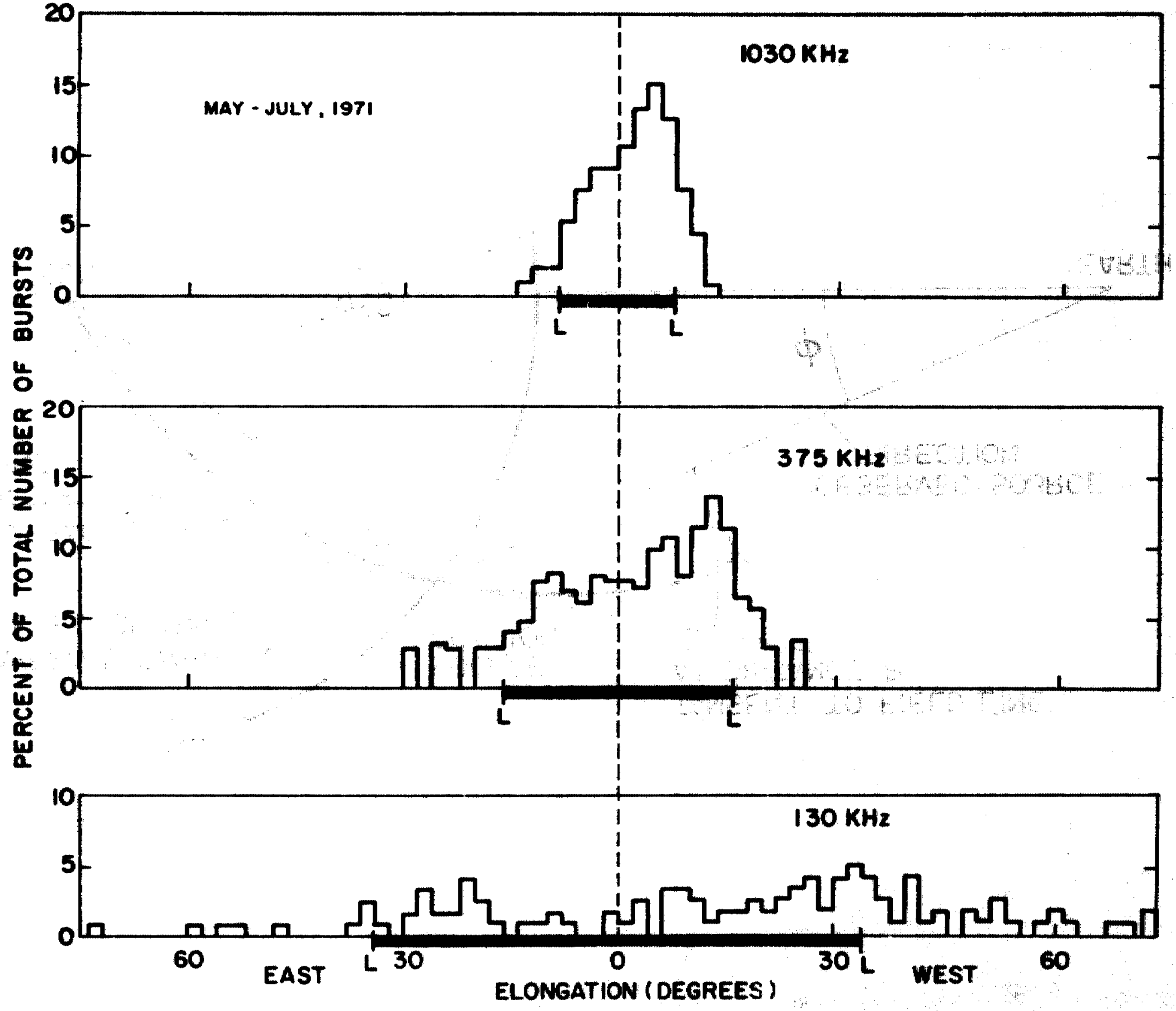
Fig. 2 Diagram showing the model emission level and magnetic field line spiral. The field line spiral was calculated for an average solar wind bulk speed equal to 400 km/sec. The angle ϕ is the observed solar elongation of the source. The magnetic field line passing through a source will be in the same direction as the observing direction when $\gamma = 0$. This occurs only for source locations west of the Sun-Earth line.

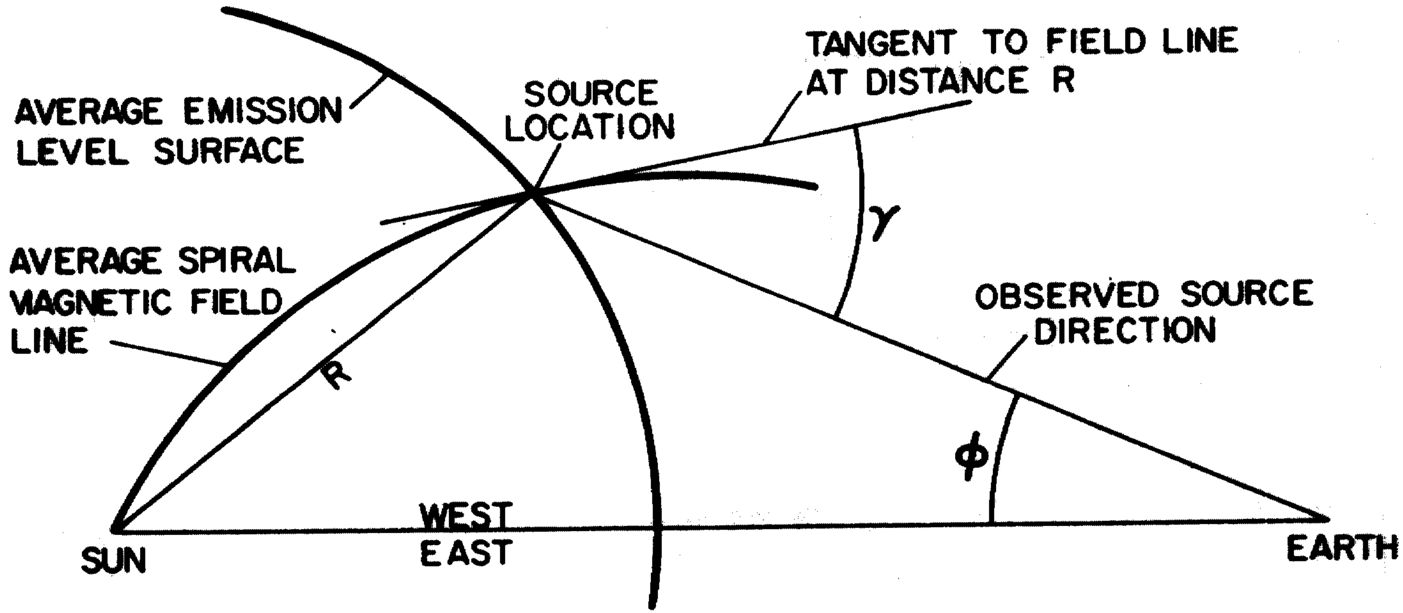
Fig. 3 The data are the means of the distribution of burst arrival directions at each observing frequency in the range 1450 kHz to 83 kHz. The source distance from the Sun at each frequency was obtained from the assumed emission level scale. The solid curve is the elongation, ϕ, of the field line when $\gamma = 0$ (See Fig . 2).

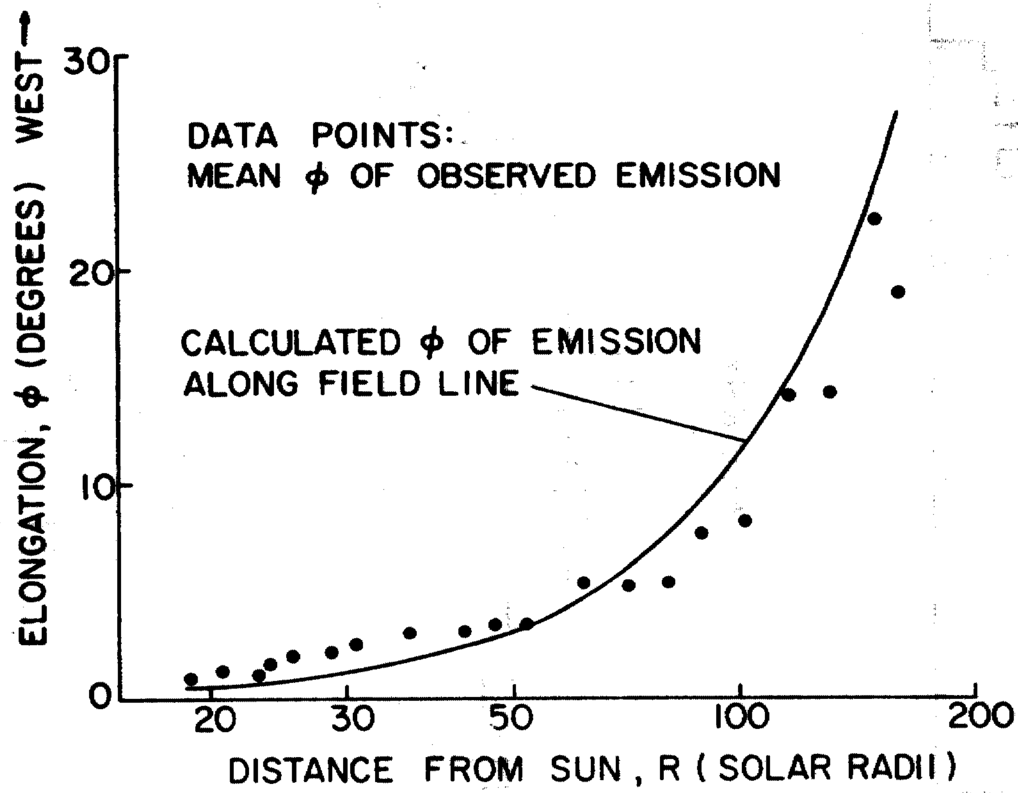
Fig. 4 Distribution of the angle γ for three representative frequencies. The angle γ was obtained from the observed elongation, ϕ, for each burst using the geometry in Fig. 2.

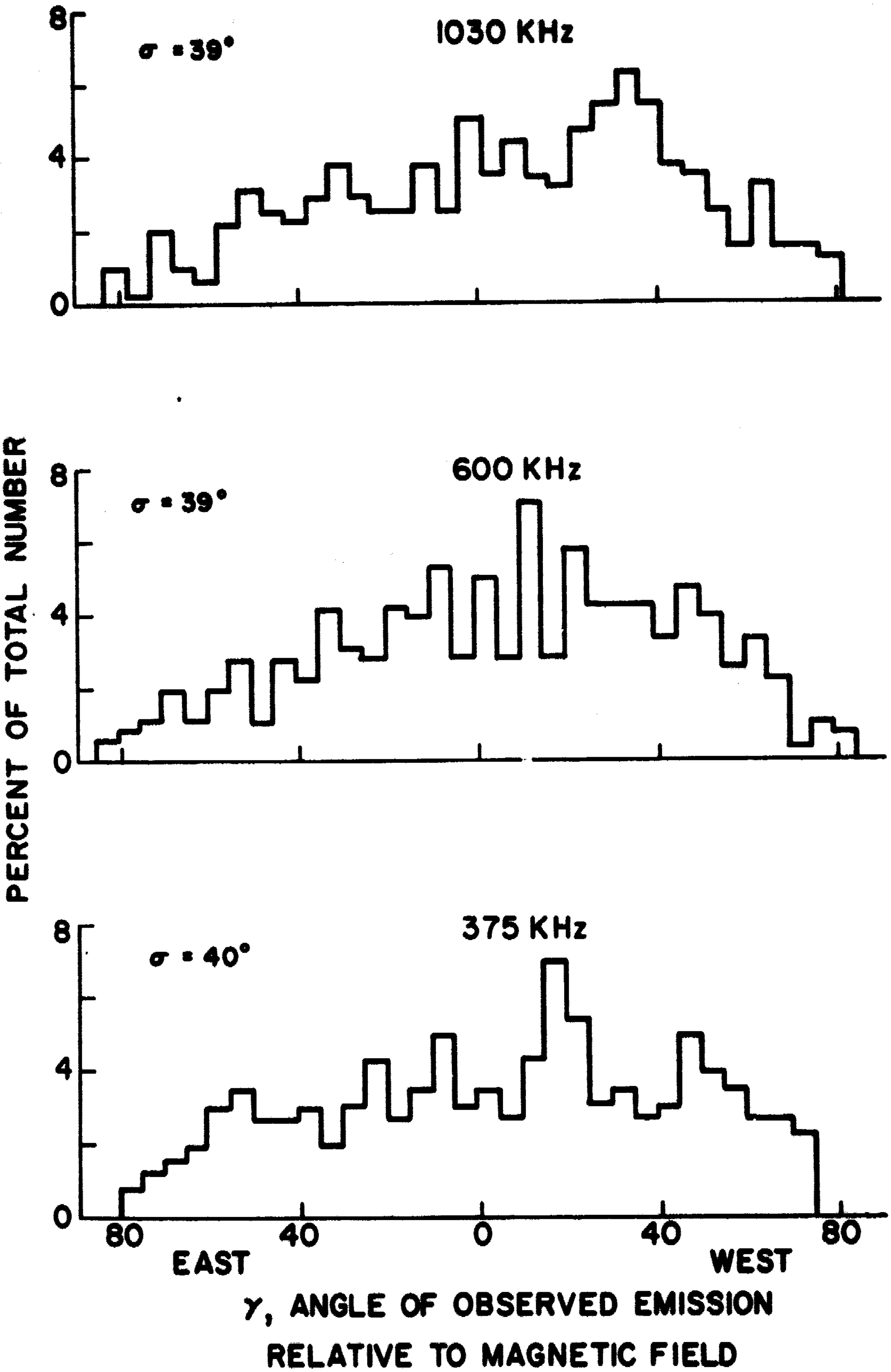
Fig. 5 The distribution of peak flux densities of type III bursts at a representative frequency during the 90 day period, May-July, 1971.

ELONGATION DISTRIBUTION OF TYPE III BURSTS




AVERAGE EMISSION
LEVEL SURFACE
SOURCE
LOCATION
TANGENT TO FIELD LINE
AT DISTANCE R
γ
AVERAGE SPIRAL
MAGNETIC FIELD
LINE
R
OBSERVED SOURCE
DIRECTION
φ
WEST
EAST
SUN
EARTH


DATA POINTS:
MEAN φ OF OBSERVED EMISSION
CALCULATED φ OF EMISSION
ALONG FIELD LINE
ELONGATION, φ (DEGREES) WEST
0
10
20
30
20
30
50
100
200
DISTANCE FROM SUN, R (SOLAR RADII)



1030 KHz
σ = 39°
600 KHz
σ = 39°
375 KHz
σ = 40°
PERCENT OF TOTAL NUMBER
0
4
8
80
40
0
40
80
EAST
WEST
γ, ANGLE OF OBSERVED EMISSION
RELATIVE TO MAGNETIC FIELD

FLUX DENSITY DISTRIBUTION OF TYPE III BURSTS